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FINAL REPORT

EIGHT-CHANNEL WIDEBAND TELEMETER

NOVEMBER 15, 1952

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GENERAL ELECTRONIC LABORATORIES, INC.

18 TREMONT STREET

BOSTON 8, MASSACHUSETTS

FINAL REPORT
EIGHT-CHANNEL WIDEBAND TELEMETER

Developed Under
Contract Nonr 882 (00)
with The Office of Naval Research

November 15, 1952

GENERAL ELECTRONIC LABORATORIES, INC.
18 Tremont Street
Boston 8, Massachusetts

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EIGHT-CHANNEL WIDEBAND TELEMETER

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PREFACE

This is the Final Report describing the development of an eight-channel wideband FM-AM telemetering system.

The system is capable of telemetering eight channels of information with a signal bandwidth on each channel of DC-10 kc. The system includes an airborne relay link for increased range.

This system was developed, and four complete systems constructed under Contract Nonr 882(00) with the Office of Naval Research.

The project was carried out on an extremely short-time schedule. Development work was begun on 15 May 1952 and three complete systems were delivered on 26 September 1952. The fourth system was completed on 15 October 1952. Approximately 6600 engineering man hours and 12,450 technician and shop man hours were devoted to the project. The following engineering personnel were engaged on a full-time or substantial part-time basis in this development: Thomas F. Jones, William J. Coughlin, John B. Donner, Stanley Forman, Earl W. Keller, John C. Martin, Arthur H. Nelson, Robert G. Rullman, Victor W. Storey and Charles A. Taylor.

Throughout the project close liaison was maintained with the Naval Research Laboratory. Acknowledgment is made of the close cooperation and assistance of Naval Research Laboratory personnel, including C. B. Cunningham, E. Bissell, M. Oleson and J. Mengel.

FINAL REPORT
EIGHT-CHANNEL WIDEBAND TELEMETER

1. INTRODUCTION

The Eight-Channel Wideband Telemeter described herein was developed, and four complete systems were constructed during the summer of 1952, by General Electronic Laboratories, Inc. under Contract Nonr 882 (00) with the Office of Naval Research.

The broad objective of this development was to provide in the minimum time four complete high-capacity multichannel telemetering systems. Each system was to be capable of telemetering eight high-capacity data channels (frequency response of each channel-DC-10 kc) with an over-all error of reproduction of less than 5 per cent. The ground range from the Terminal Transmitter to the Terminal Receiver was required to be at least fifty miles or beyond the line of sight thus requiring an Airborne Relay Station.

The design specifications are given in detail in the following section.

In addition to the severe performance specifications there was an extremely short time available for the system's design and construction. Since this schedule was so short and the required delivery date so firm, time itself became an important design factor. When a choice was presented between a circuit which was acceptable and a circuit which might prove superior, the decisive factor was the design and construction time.

The development and construction of three complete systems was completed within four months. Flight tests prior to shipment showed that the system was capable of operating as specified at short ranges with omnidirectional antennas. Indications were that directional antennas would be necessary for satisfactory operation at the specified range of 50 miles. Directional antennas with gains of 12 db each were

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The development and construction of three complete systems was completed within four months. Flight tests prior to shipment showed that the system was capable of operating as specified at short ranges with omnidirectional antennas. Indications were that directional antennas would be necessary for satisfactory operation at the specified range of 50 miles. Directional antennas with gains of 12 db each were

developed and shipped for both the Relay Receiver and the Terminal Receiver. No systems tests were made with these antennas because the test airplane was not available, but the added 24 db of antenna gain should theoretically quadruple the range of the system.

In this report the system will be described as delivered and a number of recommendations will be made for further refinement of the system.

Detailed descriptions of circuits and operating maintenance instructions may be found in "Preliminary Operating and Maintenance Notes" previously furnished.

2. DESIGN REQUIREMENTS

The Eight-Channel Wideband Telemeter was required to accept eight separate information signals at one terminal location and reproduce these signals with acceptable fidelity at a second Terminal Station at least 50 miles distant. Each complete Telemetering System was required to consist of four major subunits as follows: Terminal Transmitter, Relay Receiver (Airborne), Relay Transmitter (Airborne) and Terminal Receiver. Each complete system was required to meet the following specifications.

- a. Provide for eight separate information signals and eight corresponding calibration signals.
- b. Each individual signal channel to reproduce signal components from dc to 10 kc with not more than 3-db change in gain.
- c. Each signal channel to accept signals from +2.5 volts to -2.5 volts with an input impedance of one megohm. Provision to be made to limit signals of greater amplitude.
- d. The Terminal Receiver output corresponding to a maximum signal input at the Terminal Transmitter to be at least 100 mv with an output impedance of 500 ohms or less.
- e. The error of signal reproduction not to exceed 5 per cent of the maximum

signal as defined in item (c) above.

f. The Terminal Transmitter and the Airborne Relay equipment to operate from a 28-volt dc source. The Terminal Receiver to operate from a 110-volt, 60-cycle source.

g. The Terminal Transmitter to be designed to withstand mechanical shock to the limit of the best current engineering practice.

3. BASIC DESIGN APPROACH

A. Terminal Transmitter Station

It was clear from the wide bandwidth requirements that no existing telemeter could meet these specifications. Preliminary discussions with cognizant Naval Research Laboratory personnel resulted in the conclusion that the most probable approach was to frequency modulate the signal information onto subcarriers in the band of 2-4 Mc. Maximum deviations would be ± 50 kc or 20 kc per volt. The most serious uncertainties in this approach were whether so many channels could be operated in such close proximity without objectionable cross talk and whether the subcarrier frequencies could be adequately stabilized in the presence of temperature and voltage fluctuations, shock and vibration. A two-channel breadboard of a Subcarrier Modulator had previously been constructed at the Naval Research Laboratory which showed that temperature and voltages had to be very accurately maintained in order to prevent unwanted frequency drift and fluctuations in the subcarriers. It was also clear that great care had to be taken to shield the reactance tubes from acoustic shock and vibration, in order to prevent microphonics.

In spite of these uncertainties the 2-4 Mc Subcarrier approach was adopted and this in turn required that the transmitters and receivers have signal bandwidths of approximately 10 Mc. RF carrier frequencies in the region of 250-400 Mc were assigned. In order to expedite development, a search was first made to determine if

such transmitters and receivers were available.

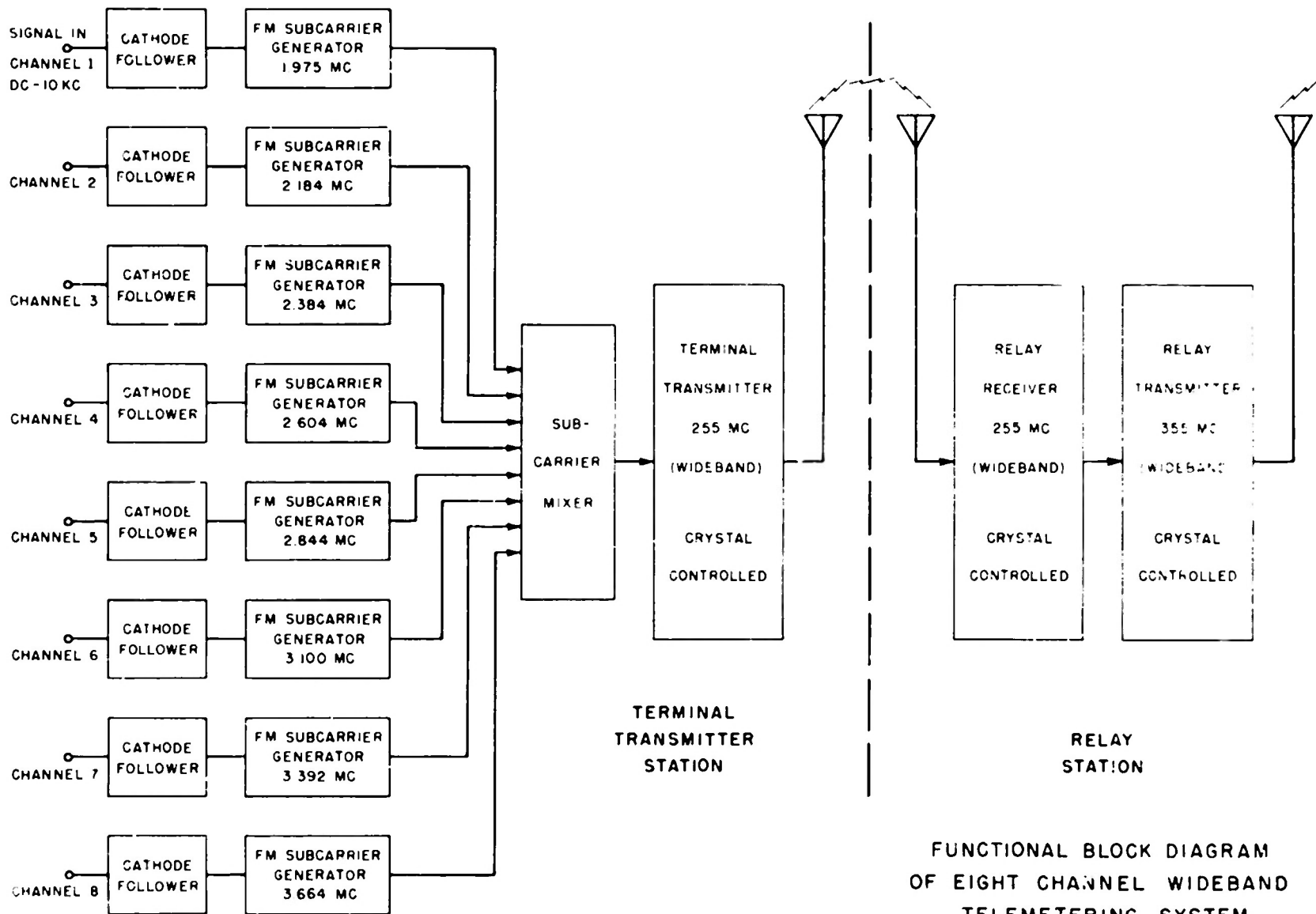
One possibility appeared to be to modify existing Block III Transmitters. These are AM Transmitters operating MOPA, originally built for portable television use, and are tunable from 200-400 Mc with a video bandwidth of 5 Mc and capable of putting out approximately 25 watts of power. It was believed necessary to crystal-control these transmitters to adequately stabilize their frequency.

Several uncertainties were involved in the use of these Transmitters. It was known that they were of old and not entirely reliable design. They required complex tuning adjustments and were not entirely stable in frequency. Their modulation linearity was questionable. In spite of these uncertainties it was decided, in order to save time, to utilize these transmitters both as Terminal Transmitters and Relay Transmitters but to modify them by installing crystal-controlled driver units. The Terminal Transmitters would operate at spot frequencies in the 250-300 Mc band tentatively chosen as 254 Mc, 266 Mc and 275 Mc. The Airborne Relay Transmitters would operate at spot frequencies in the 350-400 Mc band tentatively chosen as 354 Mc, 366 Mc and 375 Mc.

B. Relay Station

The Relay Station presented a problem of maintaining linear demodulation and remodulation on a different frequency. Several approaches were considered. One was to utilize rf amplification, detection, and remodulation in order to avoid possible distortion from heterodyne mixers and i-f amplification. It was not, however, believed feasible to obtain sufficient amplification in this way without considerable development.

Another approach which was strongly considered for the Relay Station was to develop a Relay Receiver-Transmitter Unit which did not demodulate the intermediate frequency, but heterodyned the received signal down to the i-f frequency, amplified, heterodyned up to the retransmission frequency and transmitted. This would have



FUNCTIONAL BLOCK DIAGRAM
OF EIGHT CHANNEL WIDEBAND
TELEMETERING SYSTEM

FIGURE 1

greatly simplified the Relay Station but it was felt safer in view of the time limitation, to rely upon conventional receiver and transmitter design requiring less development.

It was quite clear from the outset that existing Block III Receivers could not be used both because their frequency and phase response was not very good and because they contained a great deal of unnecessary and unwanted television circuitry.

With only 20 watts available at the Terminal Transmitter and with virtually no antenna gain, it was clear that the Airborne Relay Receiver required extreme sensitivity and must be carefully controlled at the receiver end.

Page 20, par. 6, lines 3 and 4

"antenna was a quarterwave spike five feet by four feet which was lashed across the bow of the rowboat in the center of a dural ground plane. The ground plane was about" should read "antenna was a quarterwave spike lashed across the bow of the rowboat in the center of a five feet by four feet dural ground plane. The ground plane was about"

Page 20, par. 6, line 8

The word spike should read antenna.

Page 27, par. 1, line 8

"it is suggested that meter voltage" should read "it is suggested that AGC voltage"

in either the Subcarrier Generator or the Subcarrier Demodulator could be manually compensated at the Subcarrier Demodulator.

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With only 20 watts available at the Terminal Transmitter and with virtually no antenna gain, it was clear that the Airborne Relay Receiver required extreme sensitivity and must be crystal-controlled at the same frequency as its respective transmitter. It was decided that this Receiver would be built in three well-shielded packages: A low-noise input rf amplifier, a local oscillator package containing the control crystal and frequency multipliers and a 60-Mc i-f amplifier with a 10-Mc bandwidth and a gain of 100 db containing automatic gain control. It was realized that the Relay Receiver at least must be very well shielded since it must operate in close proximity to the Relay Transmitters.

C. Terminal Receiver Station

The remaining development problem was the Terminal Receiver Station. It was decided that the Terminal Receiver could be of the same general design as the Relay Receiver, although operating at a higher frequency. It was decided that the output of the Terminal Receiver consisting of eight mixed subcarriers, would be fed to eight demodulator units. Each unit would filter out a particular subcarrier, heterodyne it to 11.5 Mc and amplify and demodulate the resultant in a standard FM i-f strip. Various methods were considered for automatically tuning the local oscillator to the desired subcarrier, but these were incompatible with the requirement that the system handle dc signals. It was felt that stable fixed tuned units could be built and any drift in either the Subcarrier Generator or the Subcarrier Demodulator could be manually compensated at the Subcarrier Demodulator.

A cathode-follower output was necessary on each Demodulator so that the +2.5-volt output of each channel could be fed at a low impedance to its respective recorder. A block diagram of the preliminary design of the entire system is shown in Figure 1.

4. DEVELOPMENT OF FINAL DESIGN

A. Terminal Transmitter Station

1. Subcarrier Generator

Detailed design of the system using the foregoing approach began toward the end

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ERRATA SHEET

EIGHT-CHANNEL WIDEBAND TELEMETER

Page iv, par. 4, line 1:

The name of Harry G. Williams should appear following that of Charles A. Taylor.

Page 6, bottom line

"sink were made, although this is not for short operating periods. All passive" should read "sink were made, although this is not necessary for short operating periods. All passive"

Page 7, par. 3, line 4

The word suppliers should read supplies.

Page 20, par. 5, line 1

The word Pawtuxent should read Patuxent.

were packed in an 18-pound aluminum heat sink. Provisions for air cooling of this heat sink were made, although this is not for short operating periods. All passive

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4. DEVELOPMENT OF FINAL DESIGN

A. Terminal Transmitter Station

1. Subcarrier Generator

Detailed design of the system using the foregoing approach began toward the end of May 1952. By late June, breadboard models of the 2-4 Mc Subcarrier Generator had been completed and tested.

The heart of the Subcarrier Generators is the deviation and oscillator circuit. Considerable effort was put into the design of these circuits. The primary aim in the development of these circuits was to provide linear deviation, eliminate cross talk between channels, and make the unit as free as possible from temperature drift, voltage fluctuation, and microphonics due to vibration and shock.

The tubes selected as reactance and oscillator tubes were Raytheon ruggedized subminiature tubes CK-5744WA. These high- μ triodes provided great deviation sensitivity and made it possible to utilize considerable degeneration in the reactance tube circuit thus providing deviation linearity over the entire range of the order of 1 per cent or better. The ruggedized subminiature tubes are rated for 1000-g shock. They are strongly built and thus not easily affected by vibration. The effect of any vibration of tube elements to change the g_m of the tube and thus the effective X_L is minimized by the degeneration provided in this circuit.

Temperature variations primarily affect the reactance tube and the L and C elements in the reactance tube circuit. To minimize any temperature change, all tubes were packed in an 18-pound aluminum heat sink. Provisions for air cooling of this heat sink were made, although this is not for short operating periods. All passive

components were insulated from this heat sink by a one-quarter inch nylon phenolic. Silver mica capacitors having a very low temperature coefficient were used.

The prototype model of the Subcarrier Generator was laid out with a view to reducing the temperature, vibration, and cross talk problems as much as possible. The entire Subcarrier Generator was laid out in a cylindrical form with each channel arranged in a 45° sector. The Signal and Calibrate inputs were located on the circumference and the circuitry proceeded toward the center where the eight Subcarriers were mixed in an adder circuit. Temperature-sensitive tubes were thus symmetrically located so that any frequency drift due to temperature rise is uniform for all channels. Cross talk is negligible since shields were mounted between channels. In order to minimize the effect of acoustic shock, the entire unit was designed to be suspended on shock cord in a larger cylinder containing a large quantity of Vermiculite acoustic material.

It was found that all Subcarrier Generator voltages had to be accurately controlled to prevent frequency fluctuations. The following means were adopted. Filaments were put on separate batteries from those supplying the dynamotors. A voltage regulator for the 108-volt and 216-volt B+ suppliers was built. Separate 216-volt regulators were provided for every four channels. It was found that there is a slight degree of cross talk (less than one-half per cent) through the 108-volt regulators at the input cathode-followers. This cross talk though not objectionable in the present design could be eliminated by using a separate voltage regulator tube for each channel.

It was found that there was some cross talk caused by the mixed subcarrier rf feeding-back into the signal input. This was eliminated by the 100-K resistor in the grid circuit of the CK-6152 cathode-follower which together with the input capacitance of the tube, filters out the radiofrequency.

Considerable care was required in selecting the subcarrier frequencies, in order to minimize cross talk between channels. A mathematical study was made of

the optimum subcarrier frequencies with a view to minimizing the number of harmonic and second and third-order cross products within the bandpass of any of the demodulators. The following subcarrier center frequencies were chosen.

Channel 1	1.975 Mc
Channel 2	2.184 Mc
Channel 3	2.384 Mc
Channel 4	2.604 Mc
Channel 5	2.844 Mc
Channel 6	3.100 Mc
Channel 7	3.392 Mc
Channel 8	3.664 Mc

In each channel a clipping circuit was utilized to clip input signals below -2.5 volts and above +2.5 volts so that the signal on one channel would not stray into adjacent channels. A lowpass filter was also installed cutting off at 10 kc. A deviation sensitivity control potentiometer was provided.

It was desired to calibrate all signal channels without switching the signal channel out of the circuit. Several methods were studied. The method adopted was to feed the calibrating signal in through a voltage divider directly to the output of the cathode-follower.

A final development problem on the Subcarrier Generator was the summing circuit for mixing the subcarrier outputs from all eight channels. Several methods were tried, but the one adopted was simple resistive summing with adequate decoupling of channels. An output CK-6152 cathode-follower was installed to feed the transmitter. The output level of this adder is only about 0.25 volt. In order to obtain about 0.7 volt of signal which is optimum for the transmitter, a video amplifier output was also designed and was installed in the second, third and fourth Subcarrier Generator Units.

Photographs showing different views of the Subcarrier Generator appear in Figures 2 and 3.

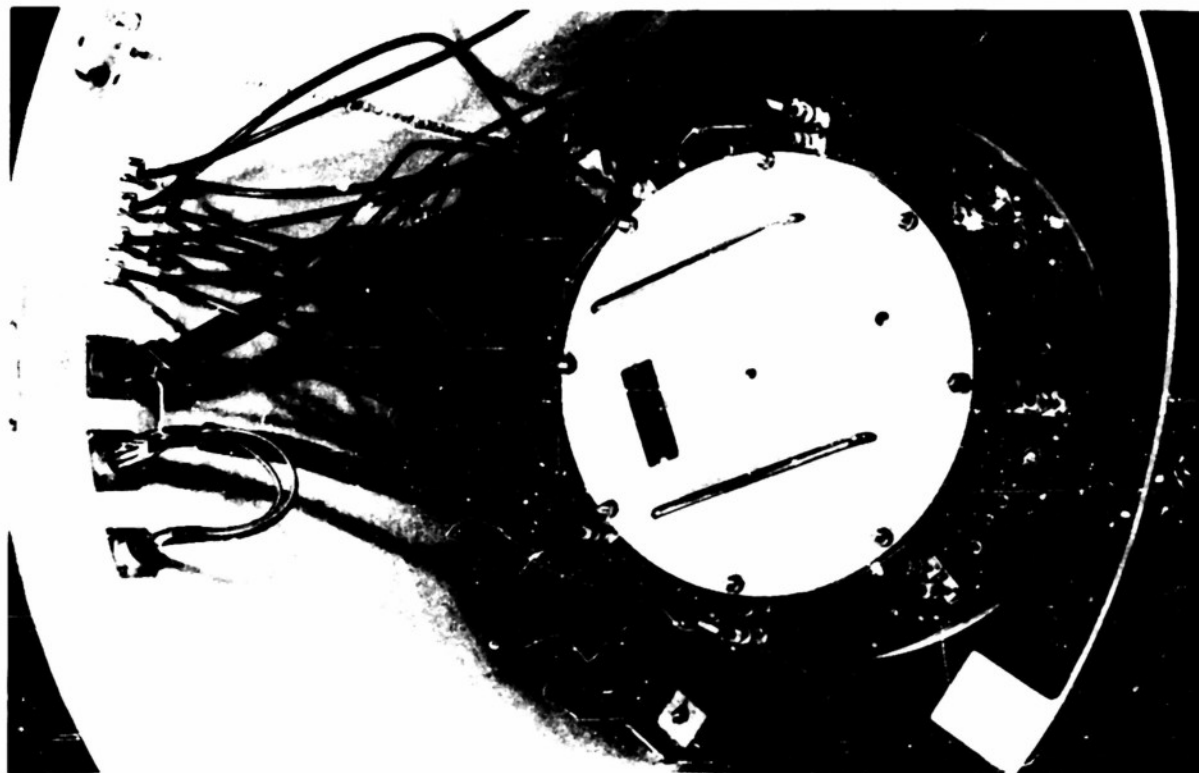


Figure 2 - Subcarrier Generator mounted in outer box

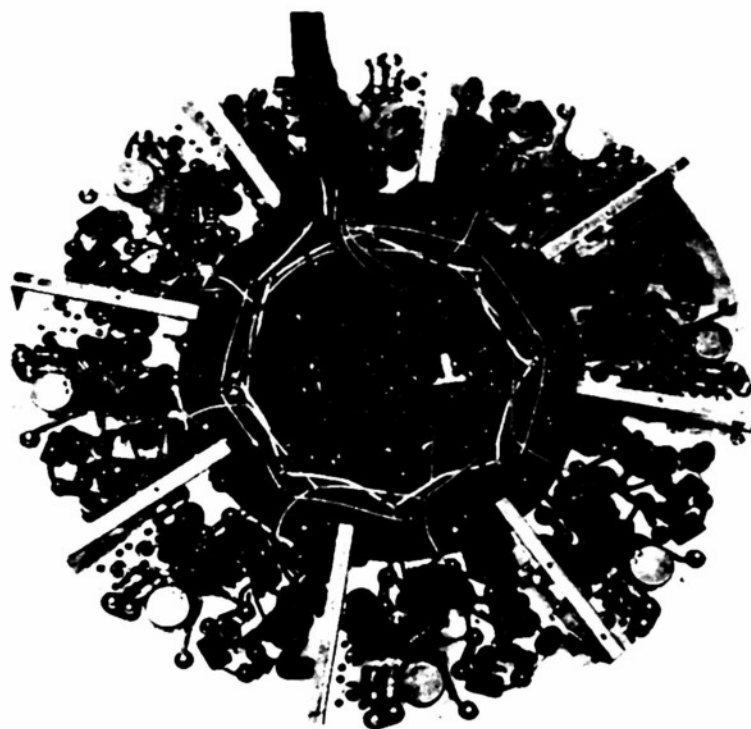


Figure 3 - Subcarrier Generator; bottom of Chassis

2. Terminal Transmitter

The Block III Transmitters were modified by taking out the television sync circuits and installing a crystal multiplier subassembly. This multiplier used 6-8 Mc crystals with a 6AQ5 oscillator and frequency doubler, an 832 tripler and an 829 tripler. The output of this subassembly was coupled into the existing 8025-A master oscillator which was modified to operate as a tripler. The output of this was then fed to the output stage consisting of two 8025-A's. Considerable input power was found necessary to make the 8025-A triple and this necessitated the 829 power driver. The final 8025-A stages were left as they were in the Block III Transmitter.

Maximum power output of 40 watts was possible on each of the spot frequencies of 254 Mc and 266 Mc. However, in order to get adequate modulation percentage, the output power was reduced to a 20-watt level.

Some study was made of the possibility of redesigning the wideband video amplifier which has a voltage gain of about 15, in order to increase the modulation percentage. It was, however, decided that 25 per cent modulation was the maximum which could be obtained by grid modulation with good linearity in this transmitter.

Very little could be done to shockproof the Block III Transmitter except wherever possible to ruggedize components and wiring. The Transmitter was found to require considerable maintenance and the 8025-A Tubes require frequent replacement. Tuning procedure is fairly complicated and should be done only when the Transmitter is hot. It was recognized throughout this development that there were many advantages to be gained by completely redesigning the Transmitter rather than modifying the Block III Transmitter, but the time schedule prevented it.

The Terminal Transmitter Station was required to operate from 28 volts dc. It was necessary to utilize two dynamotors, one for the Transmitter and one for the Subcarrier Generator. A special voltage regulator at 108 and 216 volts was designed to stabilize the voltage and prevent frequency drift in the Subcarrier Generator.

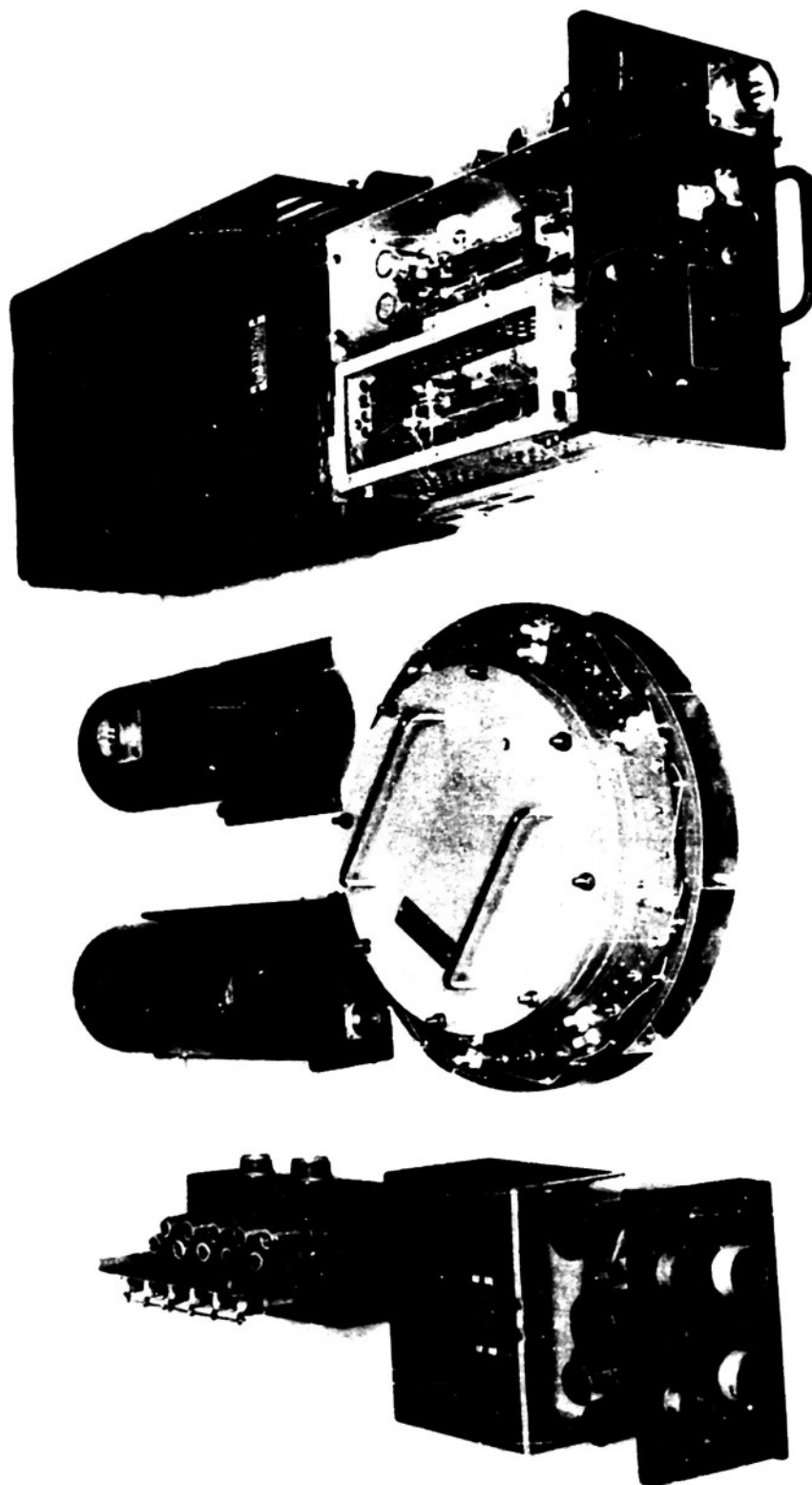


Figure 4 - Components of Terminal Transmitter Station

The physical layout of the units of the Terminal Transmitter Station was designed in close consultation with the Naval Research Laboratory, and the inter-connection system was designed to operate in conjunction with a command receiver supplied by the Naval Research Laboratory.

A photograph of the units of the Terminal Transmitter Station appears in Figure 4.

B. Relay Station

1. Relay Receiver

The design of the Relay Receiver was separated into three problems. The design of a low-noise rf stage, the design of a suitable i-f strip preferably at 60 Mc with a bandwidth of 8 Mc, a gain of about 100 db, and the design of a crystal-controlled local oscillator. Since this receiver was required to operate at fifty miles range, it was known that it must be as sensitive as possible.

An rf unit consisting of two 6BQ7 Tubes was designed, one as an rf amplifier and the other as a mixer and output stage. A search was made to find available i-f strips, in order to speed delivery. Strips having 60-Mc center frequency and bandwidth of 10 Mc were found to be in production by the General Communication Company of Boston. This unit was modified to provide AVC and a suitable detector and video amplifier in the band of 2-4 Mc.

Considerable development work went into the crystal-controlled local oscillator. Approximately 2 volts of local oscillator signal was required by the receiver. Many different circuits and tubes were tried.

Originally, the first oscillator operated at the crystal fundamental and it proved extremely difficult to eliminate this fundamental and its unwanted harmonics from the output of the local oscillator which reduced the receiver sensitivity. After further development the first oscillator was caused to operate at the third harmonic of the

crystal and three successive doubler stages were used to multiply the frequency by a total factor of twenty four.

Considerable shielding and adjustment was necessary to eliminate spurious signals from unwanted harmonics. An external oscillator, such as the General Radio Unit Oscillator may be used instead of the crystal-controlled local oscillator.

The rf unit, i-f unit and local oscillator in individual shielded packages were mounted in a shockmounted receiver package containing a power supply.

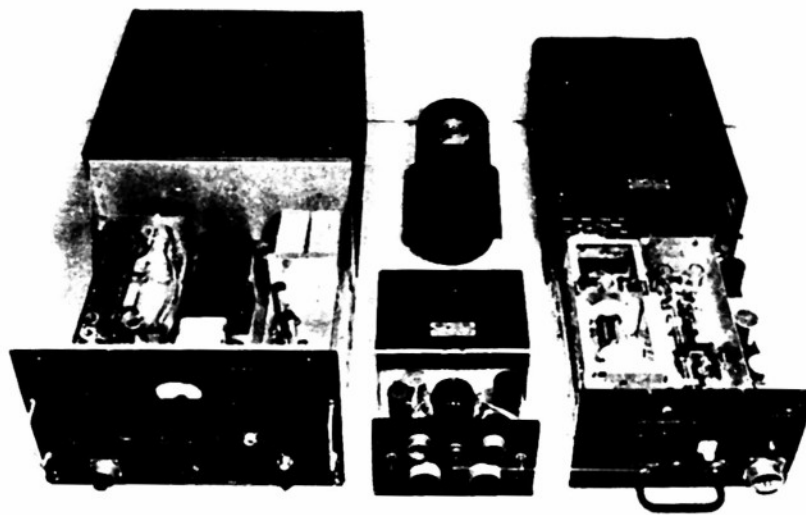
The output of the receiver is at approximately a one-volt level. A meter is provided to measure AVC voltage. A minimum detectable signal is approximately 3 μ volts.

2. Relay Transmitter

Considerable development effort was necessary in order to crystal-control the Relay Transmitter. It was found that at the higher frequencies of these transmitters (350-400 Mc) the 8025-A Tripler stage used in the Terminal Transmitter would not triple at an adequate power level. A number of different types of circuits and tubes were tried and this problem was finally solved in this stage by using an Amperex 9903 Tube. This tube operated very well, but required complete modification of the tank circuits and required the addition of a thermal delay relay to prevent high voltage from being thrown onto the screen of the 9903 until the driver is operating. The Relay Transmitter is capable of putting out up to 40 watts on the spot frequencies of 354 Mc, 360 Mc and 373 Mc.

Some study was made of modifying the video amplifier, in order to increase the modulation percentage. Up to 25 per cent modulation may be obtained by adjusting the drive to the final 8025-A's and it was decided not to go beyond this, because linearity suffers considerably.

A very serious problem in the Relay Station was that the Relay Receiver tended



front view



rear view

Figure 5 - Components of Airborne Relay Station

to be blocked by the Relay Transmitter which operates in close proximity. Most of this interference was traced to crystal harmonics radiating from the crystal multiplier unit in the Transmitter. This interference was finally eliminated by double shielding the entire Transmitter with a shielded outside box, and by choosing frequencies to minimize such interfering harmonics. A cooling fan was installed to prevent undue temperature rise in the box.

A photograph of the units of the Relay Station is shown in Figure 5.

C. Terminal Receiver Station

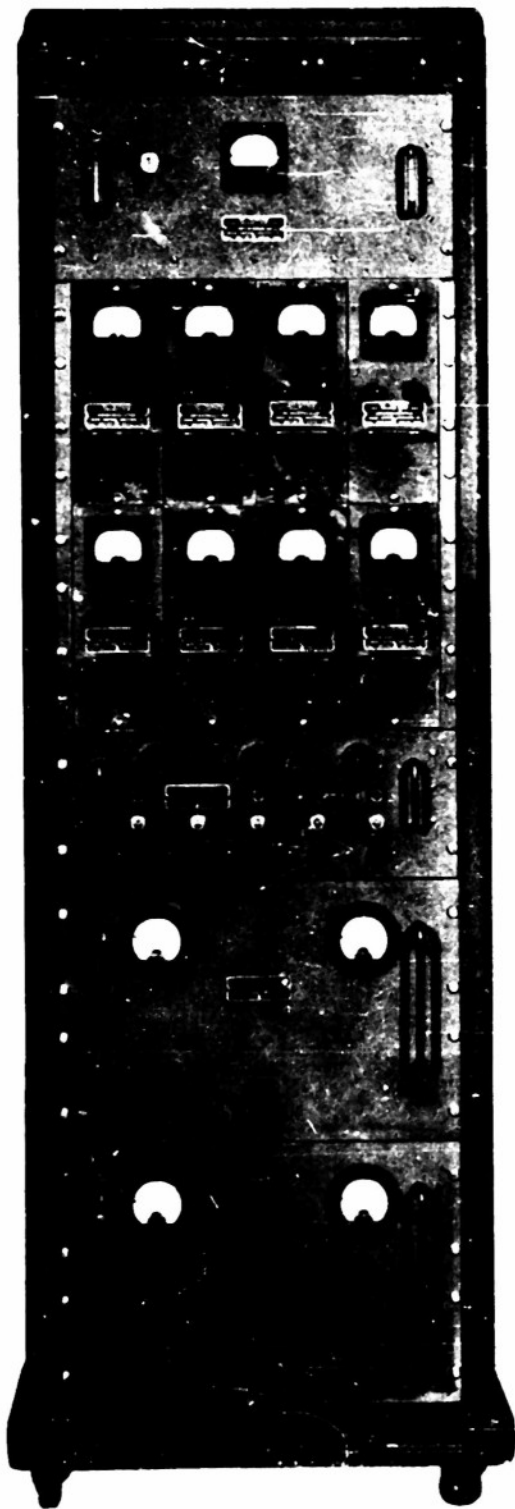
The Terminal Receiver Station was designed to receive, separate and demodulate the eight subcarriers and to feed their information to recorders.

Each Terminal Receiver Station required a crystal-controlled broadband Terminal Receiver tuned to the spot frequency of the Relay Transmitter in the band of 350-400 Mc; eight Subcarrier Demodulators each of which was tuned to select one subcarrier and amplify, limit and FM demodulate the audio information; and appropriate power supplies and control units. It was decided to mount the complete Terminal Receiver Station in a standard 19-inch Relay Rack.

1. Terminal Receiver

Design of the Terminal Receiver was necessarily somewhat different from that of the Relay Receiver. At the higher frequencies of the Terminal Receiver it was not feasible to use the same rf and mixer circuit used in the Relay Receiver. Instead, the rf stage utilized a grounded grid 5675, feeding a tuned plate cavity which contained a crystal mixer. The output was fed to a 60-Mc i-f strip similar to that used in the Relay Receiver.

The crystal-controlled local oscillator unit was similar to that used in the Relay Receiver. A crystal was operated on its third harmonic. The output was doubled in



front view



rear view

Figure 6 - Terminal Receiver Station

frequency in four successive stages and then fed to the crystal mixer. As with the local oscillator in the Relay Receiver considerable design effort went into shielding and decoupling to prevent any of the unwanted crystal harmonics passing into the Receiver. Additional trouble was encountered with the crystal oscillating in a spurious mode near the desired frequency.

The video output of the Receiver consisting of the eight mixed Subcarriers was fed by coaxial cable to distribution boxes feeding the eight Subcarrier Demodulators.

2. Subcarrier Demodulator

The development of the Subcarrier Demodulator Units was one of the major problems of this system.

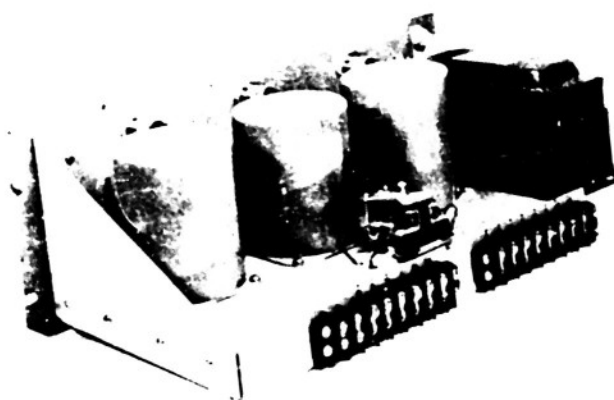
Several designs were considered. One was to build up separate amplifiers and discriminators tuned to each Subcarrier. Another was to convert all Subcarriers to a common i-f frequency and utilize a conventional i-f amplifier and discriminator. It was found that such i-f strips having 15-kc bandwidth could be obtained from the Collins Audio Products Company, and this latter method was adopted in order to save time, and to make the units interchangeable.

Despite the fact that the Subcarriers were centered an average of only 200-kc apart and deviated ± 50 kc, it was believed that adequate separation could be obtained without the use of input rf amplifiers. A very stable 6C4 Hartley Oscillator was designed, feeding a 6AS6 Converter. The output was fed into the Collins i-f Strip retuned to 11.5 Mc. An LC lowpass filter was included in the input circuit to prevent oscillator voltage from feeding back to other demodulators. An input bandpass filter was designed tuned to the frequency of the desired Subcarrier. This filter did not, however, entirely prevent adjacent channels from feeding through and it was possible to tune these channels in, thus creating the possibility of mistuning the Demodulator.

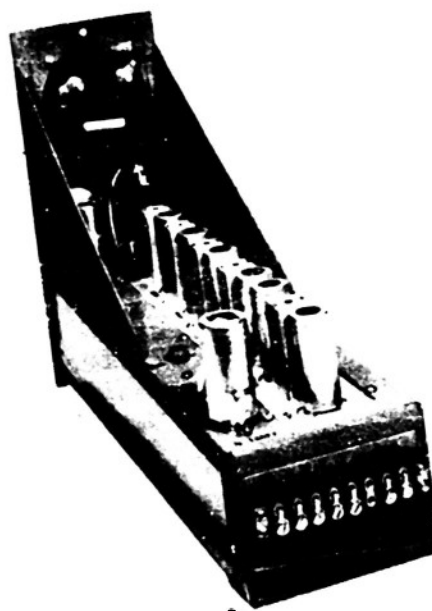
Various types of input filters were designed but this problem was not solved on



Receiver

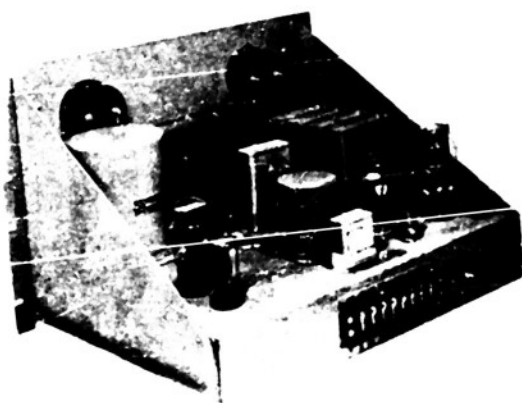


Control Panel



Subcarrier Demodulator

-150 Volt Power Supply



+150 Volt Power Supply



Figure 7 - Components of Terminal Receiver Station: Rear View

an entirely satisfactory basis. The first type was a tuned circuit with a Q of ten connected directly across the mixer signal grid. A second method was to tune two series-tuned circuits to reject the adjacent channels above and below the desired channel. A third filter increased the side channel rejection by two loosely-coupled parallel tuned circuits, one tuned to the next higher and one to the next lower channel. None of these filters was entirely satisfactory. It is probable that input rf stages would be desirable.

The i-f strips were retuned from 10.7 to 11.5 Mc to adjust the bandwidth when limiting to about 200 kc.

The units varied somewhat in sensitivity but could be made to limit on as little as 20 μ volts of subcarrier.

The output of the discriminator was fed to a cathode-follower. A zero-centered meter was utilized on the front of each unit to tune the Subcarrier to the center frequency of the Discriminator. In order to reduce the noise, a lowpass filter cutting off about 700 cps was used on all Subcarrier Demodulators on channels not requiring the full 10-kc frequency response.

Each Demodulator was able to be tuned to select out and demodulate any desired Subcarrier over the band 2-4 Mc. Some cross talk due to coupling through the power supplies was eliminated by filters in each Demodulator.

Rather extensive testing was done in the laboratory using the Subcarrier Generator to feed the Demodulators directly. In this way the linearity, frequency response, cross talk and drift of the Modulator and Demodulators could be tested independently of the radio links.

These tests showed over-all linearity of Modulator and Demodulator to be of the order of 1 per cent. Frequency response was flat within 3 db to 10 kc, as pointed out previously; on those channels without cut-off filters a Demodulator could be tuned to zero the front panel meter on the adjacent channels as well as on the desired channel, and some difficulty was had with this. It was found best to tune with an audio signal on

the Subcarrier and to look at this signal at the output of the Demodulator on an oscilloscope. When properly tuned there was negligible cross talk between channels. The minimum detectable audio signal was of the order of 0.05 volt and the maximum of the order of 2.5 volts giving a dynamic range of approximately 50. Inasmuch as the full 10-kc response was not required on most channels, lowpass filters cutting off at 1000 cps were used on most of the Demodulators, thus greatly cutting down the noise level and increasing the dynamic range to about 200.

Other units of the Terminal Receiver Station which were developed were two power suppliers and a control panel. These were fairly straightforward in design.

Photographs of the Terminal Receiver Station are shown in Figure 6. Components of the Terminal Receiver Station are shown in Figure 7.

5. SYSTEM TESTS

At various times in the course of this development, tests were held to determine operation of various parts of the system or of the over-all system.

The first of these tests was held in the last week of July at Patuxent Naval Air Test Center to determine the range at which the Airborne Relay Station could operate from the Terminal Transmitter with different types of antennas and at different altitudes.

The Transmitter, with its power supply, batteries and antenna, was put into a rowboat and allowed to drift freely upon Chesapeake Bay, clear of all objects. The antenna was a quarterwave spike five feet by four feet which was lashed across the bow of the rowboat in the center of a dural ground plane. The ground plane was about twelve to eighteen inches above the water level. The Transmitter was tuned approximately to 270 Mc and delivered 20 watts into a 50-ohm load. When connected to the antenna the loading dropped slightly but the power into the antenna was probably of the order of 15 watts. On one test a three-quarter wavelength spike was used.

The receiver was not the receiver to be used in the final system but contained most of the components of the Relay Receiver. The bandwidth was about 10 Mc and a

signal in the order of two μ volts could be detected. Two receiving antenna locations were used on the SNB test aircraft, one on the bottom of the plane and one on the top of the plane well behind the wings. In a typical flight test result, the signal falls to 10 μ volts at a range of 30 miles. However, it was found that by climbing to 12,500 feet the signal strength in this case was increased by a factor of a little over two. The conclusion from these range tests was that additional antenna gain should be provided. It was, however, desired if possible to maintain omnidirectional coverage at both the Terminal Transmitter, Relay Station and Terminal Receiver. After these tests, sleeve type antennas giving some gain in the vertical plane were designed by the Naval Research Laboratory personnel for installation in the P2V Relay Station used in later tests.

The second system test was held at Squantum Naval Air Station during the third week in August. The object of this test was to operate the entire system and see what difficulties were encountered.

For this test the Terminal Transmitter equipment at 255 Mc was mounted in a Navy Crash Boat with a vertical sleeve antenna cut to 255 Mc on a ground plane located on the after end of the boat about three feet above the water.

The Relay Station was installed in a P2V Airplane on the nose of which was mounted a vertical sleeve type receiving antenna cut to 255 Mc, and at the rear of the fuselage, two transmitting antennas cut to 355 Mc, one vertically-polarized and one horizontally polarized.

The Terminal Receiver Station was located in the Squantum Naval Air Station Electronics Shop. VHF communication was used between the various parts of the system. Inasmuch as this was the first over-all system test, considerable time was required to install the equipment and make it operate.

Several flight tests were held and it was found that the Airborne Relay Station would not operate satisfactorily because there was insufficient isolation between the Relay Transmitter and the Relay Receiver, and the Transmitter blocked the Receiver.

Various efforts were made to physically separate the Transmitter and Receiver but these did not solve the problem. It was clear that considerable effort was required in the way of shielding and filtering to make the Relay Station operate as intended.

Although the over-all system could not be tested at this time as hoped, range tests were run on the individual links. It was found that out to 50 miles a signal of about 10 μ volts was received at the Relay Receiver flying at 10,000 feet altitude, and that a signal of about 10 μ volts was received at the Terminal Receiver at a range of about 25 miles. Although these were detectable signals it was clear that they were marginal and that satisfactory operation at 50 miles or more total range was dubious.

The final system tests were held during the second week of September. In these tests both the Terminal Transmitter Station and the Terminal Receiver Station were located on the roof of the General Electronic Laboratories, Inc. building in Boston. The Relay Station was mounted in the same P2V Airplane used in previous tests and based at Squantum Naval Air Station.

The function of these tests was to determine whether the interference problem in the Relay Station had been solved by means of double shielding the Transmitter and to check over-all system operation.

In these tests it was found that the double shielding of the Transmitter did eliminate interference between Relay Transmitter and Relay Receiver, at least on the required spot frequencies. Indeed, simultaneous operation in the same airplane of two Relay Receivers at 254 Mc and 266 Mc and two Relay Transmitters at 354 Mc and 366 Mc was found possible.

In the final test on September 20, telemetering signals were fed through the entire system from the Terminal Transmitter up to the Airborne Relay Station and down to the Terminal Receiver. Audio signals were fed successively into each channel and the demodulated audio signal inspected on a cathode ray oscillograph at the Terminal Receiver. In these tests the Airborne Relay Station operated at a range of 5-10

miles from the Terminal Stations using omnidirectional antennas. It was found that so long as there was adequate rf signal strength to limit the demodulators the telemeter signals were very good. There seemed to be no detectable cross modulation between channels or distortion of the signals. It was noted, however, that when the Relay Station Airplane banked or turned in an unfavorable aspect the signals became noisy and in some cases dropped out altogether.

It was concluded from these tests that the system was sound at least so long as there was adequate rf signal strength. It was found that in order to get good operation the Demodulators should limit and it was estimated that 30- μ volts rf signal strength should be obtained at the receiver for reliable operation. As a result of these tests it was decided that additional antenna gain was the best way to increase the signal strength so that reliable operation could be obtained at ranges of 50 miles and more. It was felt that the Transmitting Antennas should be kept omnidirectional but that the Relay Receiver and Terminal Receiver Antennas could be made directional with gains of approximately 10 db each and the over-all system operation greatly improved. The Antennas could be manually pointed to maximize the received signal as indicated on the receiver AVC meter.

Because of the pressing time schedule it was necessary to deliver three complete telemetering systems without further range testing. It was decided, however, to build up directional Yagi Antennas on short notice and deliver these as quickly as possible.

6. ANTENNA DEVELOPMENT

The Antennas developed for this equipment were developed, constructed, tested and shipped on extremely short notice. No tests were made of the Antenna as mounted on the Relay Airplane inasmuch as it was not available. Free space radiation tests were made, however. Each Yagi Antenna was measured to have a gain of approximately

12 db over a standard dipole and to have a front-to-back ratio of better than 30 db. Beamwidth between half-power points in the vertical plane is approximately 40 degrees and in the horizontal plane is approximately 60 degrees.

Each Antenna consisted of two five-element vertical Yagi Antennas placed side by side. These were mounted on a rotatable mast. The Relay Receiver Antenna was designed for reception at 255-265 Mc and intended to be mounted under the nose of the P2V Relay Aircraft. It was constructed of five-eighths inch brass tubing for added strength. The Terminal Receiver Antenna was designed for reception at 355-365 Mc and designed to be mounted at the Terminal Receiver Station.

The Antenna elements were designed to feed a cable harness consisting of 95-ohm twin conductor cable, a tee connector and a 50-ohm balun. Two receivers may be simultaneously fed from one antenna if desired with, of course, some loss. A sketch of the Relay Receiver Antenna as delivered is shown in Figure 8.

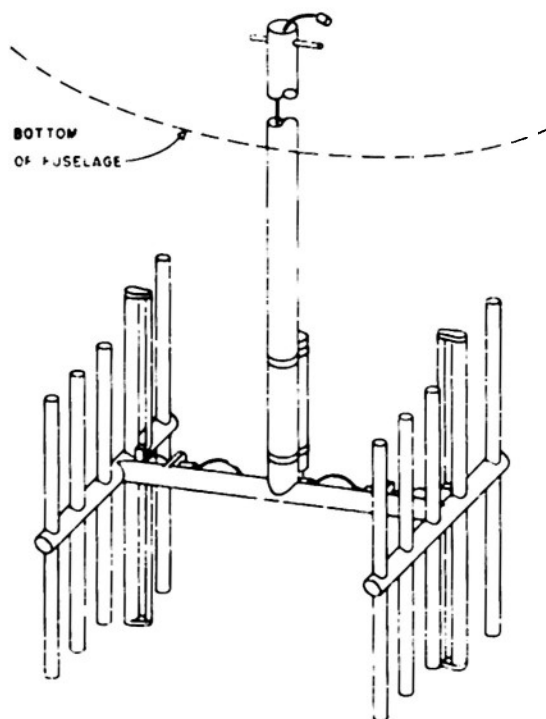


Figure 8 - 255-266 Mc Directional Antenna for Relay Receiver

7. RECOMMENDATIONS FOR FURTHER DEVELOPMENT

As previously pointed out, the system described herein was developed from its basic concept and four systems constructed on an extremely short time schedule of four months. It was generally recognized that further refinement would be necessary in order to optimize system performance and reliability.

As a result of this development it is possible to say that the system is basically sound in that it provides the desired number of channels, bandwidth and data transmission accuracy, providing it is used at ranges where there is adequate rf signal strength.

At the same time it is clear that the operation of the system can be greatly improved by reengineering certain components. The following recommendations are made.

A. Terminal Transmitter Station

1. Subcarrier Generator

The Subcarrier Generator Unit operates satisfactorily. It may, however, be made more versatile and more easily maintained by unitized construction in which the Subcarrier Generator for each channel would be packaged separately. Thus, if any channel should require repair it could be replaced without taking the other channels out of operation. Furthermore, if only four channels were needed in a particular application only four units would be used. If more than eight channels were needed, additional Subcarriers could be used, assuming that noninterfering subcarrier frequencies can be found.

The advantages of this unitized construction were recognized during this development and a unit was built up and tested. It was felt that the shock, vibration and temperature problems would be more difficult to solve in small units. It is believed that with additional time these problems can be solved with unitized construction.

Further study may be profitably made of the optimum subcarrier frequencies

and possibly higher frequency channels could be used, providing more channels within a single octave. A mechanical or electronic commutator could be used to commute several channels requiring lower frequency response onto one Subcarrier.

2. Transmitter

The unit most seriously requiring redesign is the Transmitter which presently is a modification of an old television transmitter. This unit should be redesigned specifically for spot frequency crystal-controlled application in much smaller size and to be much more rugged and reliable in operation. Serious consideration should be given to plate modulating, in order to get greater modulation percentage. The video amplifier should be redesigned. Higher rf power outputs should be considered. Frequency modulation should also be considered.

B. Relay Station

It is believed that a directional antenna at the Relay Receiver is essential for reliable long-range operation. Further work should be done to improve the antenna.

The Relay Receiver is believed to be sound with the exception of the Local Oscillator Unit. Further work should be done in the Local Oscillator Subassembly to isolate stages of frequency multiplication and prevent feed through of unwanted crystal harmonics. An Accorn Tube output stage is suggested as is the use of a higher frequency fundamental.

The possibility might be explored of heterodyning down to i-f frequency and back up to rf without detection as done in microwave television relays. If this proves not feasible, the same Transmitter designed for operation as the Terminal Transmitter should be used as the Relay Transmitter.

C. Terminal Receiver Station

The most substantial recommendation for the Terminal Receiver Station is that the Demodulator units should be reengineered to provide improved rejection of adjacent

channels and to eliminate the possibility of tuning the Demodulator to the wrong channel. It seems clear that a sharp rf input filter at the input of each Demodulator should be used. This should probably be made a part of an input rf stage. Alternatively, a channel separator unit should be built for insertion between the Terminal Receiver and the Demodulators consisting of eight filters and rf amplifiers and feeding out the separated subcarriers to the respective Demodulators. Some preliminary study should be undertaken to determine which approach should be used. To ease the tuning problem it is suggested that meter voltage be brought out to the front meter as well as discriminator voltage with a toggle switch for selection.

As in the case of the Relay Station a directional antenna should be used. The same changes incorporated into the Local Oscillator Subassembly of the Relay Receiver should be incorporated into the local oscillator of the Terminal Receiver.